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VEGETABLES AS FOOD

IT will generally be conceded that there has been a considerable increase in the production of vegetables since the beginning of the war brought about largely by their growing popularity as a supplementary source of food for the household. It seems appropriate, therefore, that attention should be drawn to a discussion on "Vegetables as Food" which took place recently in London at a meeting of the Nutritional Panel of the Society of Chemical Industry. Among the subjects (1) dealt with were the chemical composition of vegetable foods and their place in peace and war-time diets; the planning of vegetable production; the effect of cooking on the nutritive value of vegetables, and the effect of canning on the nutritive value of canned vegetables.

A report of the meeting which appeared in *Nature* (2) states, among other things, that "although root vegetables may provide carbohydrate, and green leaves supply protein of useful quality, and although pulses contribute calories, carbohydrate and second-class protein to the diet, vegetables are primarily useful as sources of vitamins A and C and iron and calcium. If the proportions of the day's requirements of each of these four factors in 4 oz. of any vegetable, cooked or raw according to how it is customarily eaten, are plotted one above the other as a column in a graph, a measure of the excellence of the article as a protective food is obtained. A series of vegetables graded in this way and arranged in order of merit is instructive. First come the green vegetables, broccoli tops, watercress, mustard and cress, Brussels sprouts and spinach, rich in carotene, very rich in vitamin C, and containing useful contributions of iron and calcium, although it is doubtful whether the calcium in spinach is utilizable. Next come cabbage and cauliflower, which still contain substantial amounts of vitamin C but negligible quantities of carotene. In green vegetables carotene is associated with greenness; when the heart of a cabbage is blanched it thereby forfeits its rank in the highest class of 'protective' vegetables. Tomato and lettuce fall in the middle of the list. They contain more carotene but much less vitamin C. The vegetables at the bottom of

(1) *Chemistry and Industry*, Vol. 60, Nos. 23, 25, 32 and 35.

(2) Vol. 147, pp. 513-514; p. 711.

the list, one-fifth as concentrated as the greens, are turnips, green peas, radish, leeks, parsnips, string beans and onions. Asparagus, cucumber, celery and marrow contain so little of vitamins or minerals that they cannot be graded at all."

The carrot as compared to the above vegetables is said to be pre-eminent as a source of pro-vitamin A. In Great Britain it is the only common foodstuff continuously available throughout the year and a single daily helping will supply the full requirement for vitamin A. While leafy vegetables may be much superior to the carrot in respect of iron and water soluble vitamins, few of them approach it in carotene content in which it is very rich.

"When the figures are compared side by side, green vegetables are more substantial providers of vitamin C than any fruit except black currants. According to the analytical figures for carotene, besides supplying the full physiological requirement of vitamin C, green vegetables can also provide all the vitamin A we need. Here is, however, a topic on which further investigation is required. To what extent is the carotene present in each plant physiologically active as vitamin A, and what proportion is absorbed by the body? Even if only 40 per cent. of the carotene present in a 4 oz. portion of watercress is physiologically available, it will still provide 50 per cent. of the total daily requirement. In spite of the lack of clear-cut evidence on the vitamin A activity of each vegetable, there are, therefore, grounds for asserting that the full vitamin A needs of the body could be supplied by vegetables should circumstances ever require it."

"Besides their importance as protective foods, vegetables could play other minor parts in war-time nutrition. A temporary glut of carrots, for example, if dried, would provide palatable carbohydrate. Although perhaps more physiological work is needed on the biological value of green leaf protein the weight of current scientific opinion seems to indicate that its value is high. Preparation of purified vegetable protein might thus provide a valuable addition to the national food supply."

"In planning war-time vegetable production there is more to do than identify and grow the crops of highest nutritional value. Yield per acre, hardiness and popularity must all be considered. Cabbages which produce heavy crops are tolerated by the public. Brussels sprouts are liked. Although education and shortage can drive people part of the way towards eating what they do not like, palatability is nevertheless important. A description was given at the meeting of how war-time vegetable production has been organized to comply with the suggestions of the Scientific Food Policy Committee. A supply of green vegetables has been assured all the year round, the acreage of carrots has been doubled, greenhouses devoted in peace-time to the growing of flowers have been converted to tomatoes and so on. Now, however, the army, the navy, the air force and the general public are insistently crying out for a vegetable product of negligible dietetic value, namely, pickles. In 1941, therefore, it was decided to plant several thousand acres of land with onions for pickling, with garlic, cauliflower, gherkins, red cabbage and mustard."

With regard to the effect of cooking on the nutritional value of vegetables data were presented on the losses, especially of vitamin C, which vegetables sustained after storage and different cooking processes. From this information it would appear that, to obtain the maximum retention of nutritive constituents, vegetables should be as fresh as possible, the waste in their preparation should be reduced to a minimum, and they should be boiled rapidly for the shortest possible time in the minimum amount of water. It was also stressed that keeping vegetables hot should most rigorously be avoided.

From results of investigations into the effect of canning on the nutritional value of canned vegetables it would appear fairly certain that canned vegetables are at least equal in nutritional value to home cooked vegetables. It is probably only in the vitamin B1 content that there is any risk of the canned product being inferior to the home cooked article but, in general, the former has the higher vitamin C content. Comprehensive feeding tests also showed that no essential nutritive factors appear to be missing from canned foods.

"The Society of Chemical Industry's discussion showed that many lacunae in the knowledge of the nutritive value of vegetables exist. Planning of vegetable production even when guided by scientific advice is a difficult task which may never reach perfection. The crucial rôle of green vegetables is to provide a very large proportion of the dietary requirement of vitamin C. Research on the physiological availability of leaf carotene is of equal importance. Just as a population is immunized against typhoid for six months or more by a single treatment, so can a country be protected against vitamin A deficiency for a winter by a single dose. The daily requirements of vitamin C, however, must be acquired daily. This is where work, investigation, inspection and analysis at every point must be organized. The chemists met the botanists, the dietitians and the administrators to their mutual benefit. The national interest would be served by the further penetration of scientific workers into the market, the communal feeding centre and the canteen."

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THE ROOT SYSTEM OF CACAO

Results of Some Preliminary Investigations in Trinidad

BY

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(*Imperial College of Tropical Agriculture*)

(I) FOREWORD

By F. Hardy

This article is mainly based on observations made by Messrs. J. A. McDonald (Chemist, Cacao Research Scheme, 1931-1936), V. I. Mulloon (Agricultural Officer, Department of Agriculture, Trinidad and Tobago ; Diploma Student, I.C.T.A., 1923-26), and C. W. R. McCreary (Post-Graduate Student, I.C.T.A., 1934-36), who have examined by the excavation method the distribution of the roots of cacao trees growing at various sites representing different soil-types in Trinidad. The records left by these investigators have not previously been published, and thanks are due to them for their willingness to allow their field notes to be incorporated into this account.

Thanks are also due to Dr. F. J. Pound (Cacao Agronomist, Department of Agriculture, Trinidad and Tobago) and to Prof. E. E. Cheesman (Botany Department, I.C.T.A.) for kindly furnishing copies of the reports written by the two last-named investigators.

The most intensive investigation of cacao-root distribution was that made by V. I. Mulloon, and this will accordingly be described first.

(II) ROOT DISTRIBUTION IN CLAY SOILS

Information supplied by V. I. Mulloon, 1936.

Two clay-soil sites were selected, representing two different important soil-types, namely :—

(A) El Reposo Estate, Sangre Grande :—*Sangre Grande Silty-Clay.*

(B) Poole Estate, Rio Claro :—*Princes Town Heavy Clay.*

Seven cacao trees were examined at the first site but only one at the second. The first-named clay soil is a river alluvial soil widespread in the Northern Plain of Trinidad* where it borders the banks of most of the rivers and streams. It also occupies the flat Sangre Grande basin. The second is a black rendzina ("humus-carbonate") soil, overlying Princes Town Marl, a calcareous sedimentary formation of Oligocene age outcropping in the undulating Naparima District of South Trinidad*. Its derived soil supports fair crops of cacao (Rio Claro District) and good crops of sugar-cane (Ste. Madeleine District).

(A) Sangre Grande Silty-Clay : El Reposo Estate

Of the seven trees excavated at El Reposo, four (Trees 1 to 4), were adjacent and occupied one bed having drains on all four sides ; two (Trees 6 and 7) were also adjacent but occupied another bed some 200 yards away from the first, and one (Tree 5) stood alone near the first group. This last tree is described as a "dud", and was chosen for purposes of comparison with the more normal trees. The age of all the trees was about 32 years.

Detailed notes were compiled for each tree, and diagrams, showing the horizontal distribution of the more important roots of six of the trees were drawn to scale, but no diagrams nor photographs depicting *vertical* root-distribution appear among the records for this site.

The main points in the descriptions are summarised in Table I, and four of the root distribution plans (for Trees 1 to 4) are reproduced as Figure 1.

Note on Table 1 : The left-hand column gives details of the descriptions. The type of tree, with height of the crown of radiating branches ("jorquette") and the kind of branching system, are stated first. The tap-root is next described in terms of the length of the main and the secondary roots and the number of forks. The number and depth of insertion of the laterals are next given, and their degree of branching is mentioned. In some cases, "anchor roots" were present; these grow vertically downwards 2 ft. from the trunk and end in 3 or 4 radiating horizontal roots at about 30 ins. depth. The fibrous rootlet system is next described, mainly with regard to its abundance and distribution. The average thickness of the soil zone in which most of the cacao roots are distributed is stated. Finally, weight and weight-ratios of main stem (trunk) to sizable roots, and of large laterals to fine roots, having diameters less than 3/16 ins., are given.

Note on Figure 1 : This shows the horizontal distribution of roots in plan for the four adjacent cacao-trees (Trees 1 to 4) surrounded

* Recent estimates show that *Sangre Grande Silty-Clay* comprises about 49,800 ac. of land in Trinidad, of which about 27,000 ac. are at present planted in cacao. The total area of Trinidad is 1,192,000 ac. of which 180,000 ac. (15.1 per cent.) are under cacao (1938). Thus the land occupied by this soil-type amounts to about 4.2 per cent. of the total area, and that part of it which is planted in cacao makes up about 15 per cent. of the total cacao area. The Sangre Grande Silty-Clay is classed as a submarginal type ; Grades II to III (medium-high) cacao productivity.

* *Princes Town Heavy Clay* occupies about 5,800 ac. of which 4,500 ac. are under cacao ; *i.e.* it comprises 2.5 per cent. of the total cacao area of Trinidad. It is classed as a good to submarginal type ; Grade I-II cacao productivity.

Table I.—Features of Root Systems of Cacao Trees growing in Clay Soils in Trinidad (After V. I. Mulloon and J. A. McDonald)

	Sangre Grande Silty-Clay								Princes Town Heavy Clay
	El Reposo (2) Disturbed (thrown-up drain soil)					El Reposo (1) Undisturbed		Las Hermanas (1) Undisturbed	Undisturbed
Tree Features	1	2	3	4	5 ("Dud")	6	7	8	9
Stem									
Habit	low-branching	low-branching with one small chupon	low-branching with one chupon	low branching	chupon	chupon	chupon	?	chupon
Jorquette ...	$2\frac{1}{2}'$	3′	14′	3′	12′	12′	14′	?	5′
Branching ...	normal	pruned	poor	normal	small	poor	small	?	open
Tap-root									
Length	20″	25″	30″	32″	38″	42″	44″	40″	50″
Secondary ...	—	—	32″	—	—	36″	42″	—	—
Forks	1	1	3	—	2	1	3	3	4
Lateral roots									
Main	6 at 4″	9 at ?	8 at 9″	5 at ?	4 at 6″	5 at 12″	5 at 7″	4 at 4″	15 at 1″
Small	2 at 12″	lot, deep	? at 20″	7, f. deep	lot at 6″	4 at 30″	? at 14″	2 at 24″	12 at 12″ 5 at 22″
Branching of laterals	good	poor	good	fair	poor	poor	poor	poor	v. good
Anchor roots ...	?	1	few	0	?	3	many	?	?
Fibrous rootlets	very abundant; uniformly distributed	sparse because of poor root development	near humic surface; lower depths, near drains; well distributed	well distributed	sparse; many small laterals, 3 ft. long terminate in net-work of surface rootlets	near surface mainly in humic layer	near surface in humic layer	?	abundant; mostly near or at soil surface; bunched at ends of thin laterals
Thickness of rooting zone	12″ (shallow)	20″	18″	20″	14″	12″	? 12″	12″	22″
Actual weights (lb.)									
Stem	128	287	216	284	63	93	161	?	226
Tap root ...	6	40	36	24	10	18	39	?	28
Laterals & fine roots	30	85	49	61	9	27	43	?	38
Ratios :—									
Stem / Laterals	4·3	(3·4) pruned	4·4	4.6	(7.2)	3·4	3·7	?	6.0
Large laterals / Fine roots	2·7	4·7	1.8	3.2	(2.5)	3·5	5.6	?	1.7

EL REPOSO ESTATE
(Sangre Grande Silty-Clay Soil - Type)

FIGURE 1

Horizontal distribution of cacao roots

LAS HERMANAS ESTATE
(Sangre Grande Silty - Clay Soil - Type)

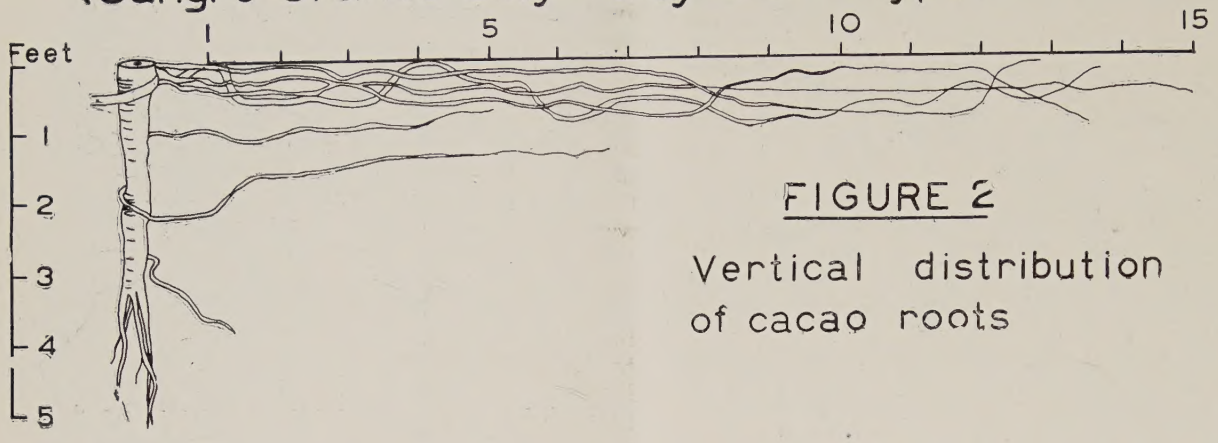

FIGURE 2

Vertical distribution of cacao roots

RIVER ESTATE
(River Fine Sand Soil-Type)

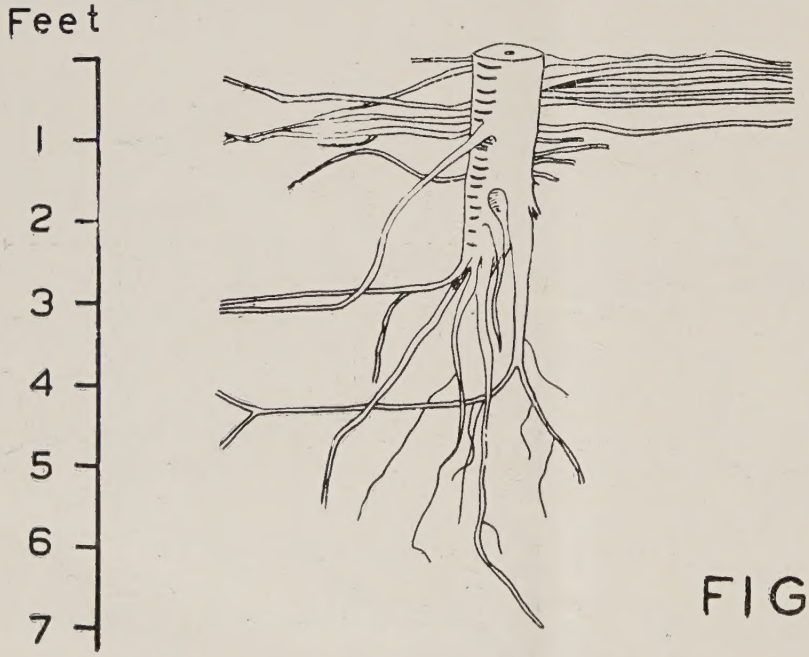

FIGURE 3

Vertical distribution of cacao roots

on all sides by drains. The trees were about 12 ft. apart; their positions are indicated by numbers and crosses. The individual root systems are shown separately, whereas, in point of fact, they actually overlap and intermingle. Medians are indicated by dotted lines; they are really coincident for each of the four sections of the diagram; the root systems should therefore be regarded as all occupying any one of the four sections. The figure clearly shows the extent of encroachment of the individual root systems one on the other; it is evident that this is considerable.

Conclusions.—The following generalisations are mainly taken from Mulloon's summary:

(i) Cacao trees having a low-branching habit (Trees 1 to 4) produced the shortest tap-roots (average length 27 ins., against 41 ins. for chupon trees)*.

(ii) Most of the laterals were given off from the tap-root at depths not exceeding 18 or 20 ins., and the bulk of the branch roots occupied the upper 16 ins. layer of soil, though the greatest number of fine roots and fibrous rootlets was confined to a relatively shallow surface layer, the majority occurring in the surface itself.

(iii) The horizontal spread of laterals varied only slightly from a mean of about 16 ft., but many roots attained a total length well over 20 ft., because of meandering.

(iv) Most of the lateral roots were directed toward the centre of the bed, few toward the drains. Those directed toward the drains were generally the deeper (*i.e.* 24 to 30 ins. depth).

(v) The frequency of branching of laterals varied appreciably, but it was not obviously decided by any distinctive feature of the soil or the tree.

(vi) The fibrous rootlets tended to be associated with soil humus; they were especially abundant where plant residues (for example, banana stumps) lay rotting on the ground.

(vii) The presence of vertical anchor roots was characteristic, though all trees did not produce them.

(viii) The deeper laterals were mostly tortuous and relatively short. The unsatisfactory "dud" tree (No. 5) differed from the others in the paucity of main laterals and the abundance of short, thin, secondary laterals. These grew out horizontally from the tap-root at 6 ins. depth and extended about 3 ft. outwards, and eventually formed a close net-work of fine roots 2 ins. below the soil surface.

* It was discovered that Trees 1 to 5 had occupied beds that had been built up by "round-ridging", whereas Trees 6 and 7 had occupied a bed whose soil had not been disturbed, hence the grouping of Trees 1 to 5 as characteristic of "disturbed" soil and of Trees 6 and 7 as typical of "undisturbed" soil in Table I. —F.H.

(B) Princes Town Heavy Clay: Poole Estate

The single tree at Poole Estate, Rio Claro, (*See* Table I; Tree No. 9, last column) whose root system was described by Mulloon, differed markedly from the trees growing at El Reposo in that the number of good-sized laterals was very much greater (32 against about 7). The laterals were inserted into the tap-root at three distinct levels, namely, 15 large laterals at 0 to 6 ins., 12 medium-sized laterals at 9 to 15 ins., and 5 small laterals at 20 to 24 ins. The first set comprised roots of diameter $\frac{3}{4}$ ins., with a spread of 8 to 12 ft. These roots branched freely within the upper 10 or 12 ins. of soil, but their finer roots were mostly situated near or at the soil surface. Each small root ended in a bunch of fibrous rootlets, somewhat remote from the parent tree. The second set of laterals, diameter $\frac{1}{2}$ ins., likewise branched freely, and the branches tended more to approach the soil surface the greater their length. The third set also branched freely (unlike the deeper laterals at El Reposo), but their spread was only about 5 feet. They were not tortuous, but more-or-less straight and normal in appearance, implying a lesser degree of resistance to growth.

(III) ROOT DISTRIBUTION IN TWO CONTRASTED SOIL-TYPES; CLAY v. SAND

Information supplied by J. A. McDonald, July, 1934.

The root systems of two typical healthy cacao trees were excavated at each of two contrasted sites, namely:—

(A) Las Hermanas Estate, San Rafael:—*Sangre Grande Silty-Clay.*

(B) River Estate, Diego Martin:—*River Fine Sand.*

(A) Sangre Grande Silty-Clay: Las Hermanas Estate

This soil-type is the same as that occurring at one of Mulloon's sites, although Las Hermanas is not situated, like El Reposo, in the Sangre Grande basin, but about 12 miles westward, on the banks of a tributary of the Caroni River. No descriptive notes of root distribution at Las Hermanas are available, but two diagrams drawn to scale (one is here reproduced as Figure 2), and a photograph were filed; these clearly indicate the similarity in cacao root-distribution at the two clay sites. Notes on one of the trees, based on a diagram and the photograph, are included in Table I (Tree No. 8) for comparison with Mulloon's records.

As at El Reposo (especially Trees 6 and 7), the total number of laterals was small, and all were inserted in the tap-root at levels above 6 ins. They spread outwards 13 to 15 feet., though occupying only the surface 12 ins. of soil. Three other smaller tortuous laterals were deeper-seated but they did not spread far. The tap-root penetrated fairly deeply and ended in several

forks which descended to 60 ins. In these and most other respects, the features of the root system of Tree 8 at Las Hermanas closely resembled those of Trees 6 and 7 at El Reposo.

(B) River Fine-Sand : River Estate

This soil, typically represented at the Government Experiment Station in the Diego Martin Valley, is characteristic of the river alluvial flats ("vegas") of the Northern Range of Trinidad, where it once had a reputation for high productiveness for cacao*.

It is a uniform, very deep sandy soil, derived from quartzose and micaceous residues of weathered Northern Range schists.

Rough notes are available describing root distribution for two cacao trees growing at River Estate, as well as three diagrams and three photographs. A typical case is here illustrated in Figure 3, drawn from one of the photographs.

The trees were 30 ft. tall and 7 ins. diameter at the base of the trunk; they were of the low branching type. Their age was about 30 years. The tap-roots were stout and cylindrical to 24 ins. depth where they divided into many forked branches each of which divided further and eventually terminated in a deeply-penetrating vertical root. Several of these were traced to 84 ins. depth, and even then their ends were not reached. Woody laterals roots were plentiful in the surface 12-ins. layer. In one of the root systems (Figure 3), 15 horizontal laterals were counted in this layer, including a group of five that came off all on one side within a vertical distance of 6 ins. from the soil surface. Numerous other thin horizontal laterals occurred in the next 12-ins. layer, as well as others in still deeper layers. Their spread was between 6 and 10 ft.

Fibrous rootlets were abundant (judging by one of the dissection photographs) and took the form of bunches at the ends of ultimate lateral branches. The depth of the main rooting zone was about 20 ins.

(IV) ROOT DISTRIBUTION IN DIFFERENT SOIL-TYPES

Information supplied by C. W. R. McCreary, 1936

The sites at which cacao-root distribution was examined by McCreary were seven in number, comprising six different soil-types representative of considerable areas of cacao land in Trinidad, as follows:—

	Estate	*Soil-type*
(A)	(1) El Reposo, Sangre Grande	...*Sangre Grande Silty-Clay.*
	(2) Las Hermanas San Rafael	... *do.* *do.*
(B)	Santa Severa, Brasso	*Ecclesville Clay** ("*Bad Brasso Clay*")
(C)	San Juan, Gran Couva	*Montserrat Loam*† ("*Brasso Sand*")
(D)	San Juan, Gran Couva	*Montserrat Clay-Silt*† ("*Chocolate Soil*")
(E)	River, Diego Martin	...*River Fine Sand*
(F)	Ortinola, Maracas	...*Maracas Sand*‡

This list of soil-types covers most of the important cacao soils in Trinidad. It includes River Fine Sand, occurring at River Estate, and Sangre Grande Silty-Clay, occurring at El Reposo and at Las Hermanas, in which cacao-root distribution had previously been examined by Mulloon and McDonald.

Ecclesville Clay (including what has formerly been called "Bad Brasso Clay") is derived from pale-grey, non-calcareous siltstone, occurring mainly in the southern part of the Central Range and the eastern part of the Naparima District of South Trinidad. It is a yellow-brown heavy soil, exhibiting a mottled rusty-brown and grey "gley" at shallow depth, implying severely impeded drainage.

Montserrat Loam (formerly known as "Brasso Sand") is a tawny-brown mineral-rich soil of variable texture resembling Chocolate Soil in some respects, though typically a medium-fine sand. It is derived from thinly-bedded glauconitic siliceous sandstone usually lacking lime.

Montserrat Clay-Silt ("Chocolate Soil") is a bright red-brown clay, undoubtedly the most fertile natural soil in Trinidad and capable of producing high yields of cacao without the aid of artificial manures. It is derived from green glauconitic sandstone rich in calcareous Miocene fossils. It shows close relationship with Rendzina ("humus-carbonate" soil).

Maracas Sand includes an extensive hilly phase utilised for cacao-growing on the lower slopes of the Northern Range. It is a red to orange or yellow loamy-sand derived from quartz mica schists. It is very variable in texture. Possibly the soil at the site examined is a colluvial or alluvial phase of Maracas Sand.

River Fine Sand, already described, is an alluvial derivative of the last.

* *River Fine-Sand* comprises about 6,600 ac. of land, of which some 1,000 ac. are under cacao; *i.e.* about 0.6 of the total cacao area of Trinidad. It is classed as a good type, Grade I productivity. This soil-type has been sub-divided by Dr. E. M. Chenery as the result of his recent soil-survey of River Estate. From McDonald's description, the site of the excavations was in *North Post Sand*, which differs little in main features from River Estate Loamy-Sand, said to be the best soil at River Estate.

* *Ecclesville Clay* (or Bad Brasso Clay) occupies about 25,650 ac. of which 14,500 ac. are in cacao cultivation, or 8 per cent. of the Island's total cacao acreage. It is classed as Grade III cacao soil (sub-marginal), much of it being prone to landslip.

† *Montserrat Clay-Silt* (Chocolate Soil) and *Montserrat Loam* (Brasso Sand) together comprise only about 3,150 ac. of which 2,800 ac. are in cacao, or about 1.5 per cent. of the whole cacao area. These soils are classed as the best cacao soils in Trinidad.

‡ *Maracas Sand* is a part of the Northern Range Loams which occupy nearly 100,000 ac. of hilly land. About 14,000 ac. of this area are in cacao out of 180,000 ac. in Trinidad under cacao (1938), or about 7.7 per cent. of the whole cacao area. Half of it is classed as Grade I and II, and half as Grade III (submarginal).

Table II.—Features of Root Systems of Cacao Trees growing in Different Soil-types in Trinidad

(After C. W. R. McCreary)

Tree Features	Sangre Grande Silty-Clay		Ecclesville Clay	Montserrat Loam	Montserrat Clay-Silt	River Fine Sand	Maracas Sand
	El Reposo (3) A (1)	Las Hermanas (2) A (2)	Sta. Severa (B)	San Juan (1) (C)	San Juan (2) (D)	River (2) (E)	Ortinola (F)
Stem							
Age of tree	20 yrs	27 yrs	22 yrs	?	25 yrs	25 yrs	25 yrs
Habit	chupon	chupon	chupon	chupon	chupon	chupon	chupon
Jorquette	3¼′; 6½′	5¾′	6′	2½′	5¾′	6½′	?
Branching	normal	normal	normal	normal ; 4	good ; 4	normal ; 4	normal
Diameter	6″	7½″	6″	6½″	7″	7½″	?
Tap-root							
Length	18″	24″	10″	14″	15″	48″	48″
Secondary	—	1 at 36″	2 at 41″	3 at 36″	—	—	—
Forks...	2 at 33″	2 at 39″	2 at 48″	—	2 at 31″	2 at ?	—
Lateral roots							
Main (*a*)	9 at 0″	6 at 3″	7 at 1″	some at 3″	few at 4½″	9 at 3″	some at 6″
,, (*b*)	2 at 8″	5 at 7″	5 at 4″	—	lot at 14″	10 at 9″	few at 12″
,, (*c*)	—	2 at 10″	—	—	—	—	—
Small (*d*)	9 at 12″	lot at 12″	8 at 7″	some at 9″	—	16 at 15″	— (gravel at 24″)
Branching of laterals ...	abundant ; poorly developed	abundant ; well developed ; stout	sparse ; thin and long	?	sparse ; large but few	fair	?
Fibrous rootlets	fairly abundant ; in litter as well as top 6 ins.	fairly abundant ; mainly in thick litter	sparse, in upper part of 5″ humic layer	fairly abundant ; evenly distributed in humic layer	abundant, especially in rotting wood	mostly in a mulch-trench ; few in soil surface	abundant in added bush mulch
Thickness of rooting zone ...	12″	12″	8″	12″	20″	18″	9″

None of McCreary's drawings and photographs of root-systems of cacao growing in these soils unfortunately is now available, but fairly full field notes were filed, and from these the following abstracts have been taken with but little modification. The information is also summarised in Table II, following the plan of Table I.

Abstracts from Notes on Cacao Root-systems in Different Soil-types (after C. W. R. McCreary)

(A) Sangre Grande Silty-Clay

(1) El Reposo Estate

Lateral roots were poorly developed, but they all showed a unique branching habit, a stout lateral dividing into 4 or 5 roots and each dividing again, the branches eventually ending in tufts of fibrous rootlets. There were 3 whorls of laterals, two, having stout members, coming off at the soil surface and at 8-ins. depth. A whorl of smaller woody roots came off at 12 ins. The *tap-root* was large ; it forked at 18 ins., and one member forked again at 33 ins., All vertical roots ended abruptly at about 36 ins., in the mottled grey subsoil. *Fibrous rootlets* occupied the top 6 ins. layer, though most occurred in a thick surface mulch. They were less plentiful on the drain side of the bed than towards the centre.

(2) Las Hermanas Estate

The *lateral roots* were large and extensive, being better developed than at any other site investigated. Most of them occurred in the top 6-ins. layer, though a few were found between 6 and 10 ins., and some even below 12 ins. The *tap-root* branched at 16 ins.,; the main root penetrated to 24 ins., and then forked and subdivided again, all verticals ending at 39 ins. *Fibrous rootlets* mainly occurred in the surface three inches, which were richly humic. Most roots trended towards the centre of the bed away from the drains.

(B) Ecclesville Clay ; Sta. Severa Estate

All the *lateral roots* here were thin and long and extended beyond the drains situated 10 ft. from the tree. Out of a total of 20 laterals, 12 occurred in two whorls within the top 6 ins. ; those below were much smaller. Some passed under a drain and there branched freely. The *tap-root* was well developed (the best seen) ; it forked at 10 ins., then again at 18 ins. One branch bent horizontally, another penetrated vertically to 42 ins., and another divided repeatedly at 24 ins., ; some sub-branches penetrated to 48 ins., *Fibrous rootlets* were sparse and evenly distributed in the upper 5 ins. of the humic soil which was thinly covered with litter.

(C) Montserrat Loam (Brasso Sand) : San Juan Estate

The majority of the *lateral roots* occurred in the top 6 ins. ; a few small laterals came off in ill-defined whorls down to 12 ins. ; they were regularly disposed around the tap-root which was well formed and penetrated to 36 ins. It tapered below 14 ins., and produced several short laterals ; the main root ended abruptly. *Fibrous rootlets* were evenly distributed in the humic layer.

(D) Montserrat Clay-Silt (Chocolate Soil): San Juan Estate

Roots in this soil were not solely confined to the top 6-ins., nor were they more numerous on the drain side of the bed. The first whorl of *lateral roots* was given off at 4½ ins. ; these roots were relatively few in number, though stout. A second whorl was given off at 13-15 ins.; these roots were somewhat smaller but more numerous. Some of their branches penetrated to depths greater than 15 ins. The *tap-root* was insignificant and only 31 ins. long. *Fibrous rootlets* were distributed mainly over the soil surface ; they were concentrated in a rotting log. They were also evenly dispersed through the humic layer.

(E) River Fine Sand : River Estate

The main *lateral roots* were very numerous and evenly disposed around the tap-root. They were grouped in three indefinite whorls ; all the stout laterals occurred in the top 12-ins. layer, but numerous small laterals came off at 13-16 ins. depth. Many of the roots where they approached a drain bent downwards to the level of the drain-bottom (24 ins.) and then assumed a horizontal course again. The *tap-root* persisted to 48-ins., where it forked. Numerous vertical chupon roots surrounded it, penetrating to 12 ins. Occasionally a lateral root sent down an anchor root. *Fibrous rootlets* were mostly concentrated in two mulch-trenches ; few occurred on the soil-surface ; some were matted within an open drain.

(F) Maracas Sand : Ortinola Estate

The soil here had been fairly heavily mulched ; it had a rich organic layer, 6 ins. thick, in which the majority of the roots were concentrated. Below 6 ins. the soil was pale-coloured ; gravel occurred below 24 ins. The *lateral roots* were evenly inserted round the tap-root and extended beyond the trenches situated 6 ft. away. They came off in two whorls, at 6 and 12 ins. The second set was insignificant in size and many members bent vertically downwards near the tap-root. Scarcely any laterals went deeper than 12 ins. The *tap-root* was well formed ; it was cylindrical to 12 ins. below which it tapered and twisted to 48 ins. *Fibrous rootlets* mostly occupied the thick layer of mulch.

Note : A photograph of half of the root-system of a 5-year old seedling cacao tree grown at the College in a sandy soil similar both to Maracas Sand and to River Fine Sand, was reproduced to illustrate a short article by Prof. E. E. Cheesman which appeared in the Fifth Annual Report on Cacao Research, I. C. T. A., 1936. It is herewith republished (Figure 4), since it indicates clearly the relationship between tap-root and laterals of a cacao tree growing in this kind of soil. This root excavation was also made by McCreary.

The picture shows that all the main laterals came off within 6 ins. of the soil surface, though numerous vertical or inclined roots penetrated to 24 ins. or deeper.

FIG. 4—Root system of cacao grown in deep sandy soil : College Botany plot (5 yr. old seedling tree; one-half cut away.

Conclusions.—The following generalisations may be drawn from McCreary's notes :—

(i) The best-formed tap-root was developed in the most clayey of the soils (Ecclesville Clay) by a tree producing the least amount of cacao.

(ii) The worst-formed tap-root was developed in the best and most productive soil (Montserrat Clay-Silt or Chocolate Soil).

(iii) The majority of the lateral roots were confined to the humic layer; few came off below 12 ins., except in Montserrat Clay-Silt (Chocolate Soil) and River Fine Sand, where deeper-seated laterals were plentiful.

(iv) The stoutest laterals were given off nearest the soil surface, and whorls of laterals of progressively diminishing thickness and length were given off at successively lower levels.

(v) A positive relationship seems to hold between the depth of organic penetration and the distribution and development of cacao roots.

(vi) Fibrous rootlets were entirely restricted to humic soil; few occurred in mineral non-humic soil. Their quantity and density varied with the amount of organic débris (litter or mulch) covering the soil surface. They were especially abundant in places where fallen branches, tree-trunks or banana stumps were rotting, and in mulch-trenches (at River Estate) where waste vegetation had been lightly buried.

(V) RELATIONSHIP BETWEEN CACAO ROOT DISTRIBUTION AND SOIL CHARACTERS

BY F. HARDY

(1) Introduction

From the foregoing account, it is evident that the distribution, development and morphological features of the root systems of cacao trees growing in Trinidad are closely linked with the characteristics of the soil. Although no attempt was made by the root investigators whose results have been presented in the last three sections to include the soil in their field descriptions, it is evident from their incidental notes and from our own knowledge of the soil-types involved, based on a large amount of detailed field and laboratory data accumulated over many years, that this root-soil relationship is very close. It was possible to identify most of the actual sites of the excavations, and thus to augment already existing information by additional data procured by further investigations in doubtful instances. The results of this research are presented in the following account.

The main features of the soil-types as developed at or near the sites of the root excavations are set out in Table III. Herein the laboratory data for the top 12 ins. layer have been summarised from the full soil profile data. This 12 ins. zone seems to contain most of the roots in practically all cases.

The sites are arranged in Table III in order of increasing productivity for cacao, based on general information relating to the several soil-types.

In *Column* 1 is given the productivity grade in accordance with an arbitrary scheme set out at the base of the table.

In *Column* 2 is given the annual approximate yield, in lb. of dry cacao beans per acre of land carrying 300 trees, comprising soil of the type and kind occurring at each site.

In *Column* 3 is given the thickness of the main rooting zone, abstracted from the root-distribution data contained in Tables I and II.

In *Column* 4 is given the approximate thickness of the humic layer of soil at each site. To obtain this value, the detailed profile data for organic matter content, usually determined for the 0-1½, 1½-3, 3-6, 6-12, 12-18, 18-24 ins. layers respectively, were plotted on squared paper

Table III.—Relationship between Soil Constants and Thickness of Rooting Zone in Different Cacao Soil Types

(Sites arranged in order of increasing productiveness)

Site	1	2	3	4	5	6	7	8	9	10	11
	Productivity for Cacao		Thickness of main rooting zone (ins.)	Humic Soil		Top 12-ins. layer of soil					
	Grade	Av. Yield (lb. ac.)		Thickness of humic layer (ins.)	Average Organic Matter Content (%)	Index of Texture (I.T.)	Reaction (pH)	Organic Matter Content (%)	Total Nitrogen (%)	Avail. phosphate (P_2O_5) (p.p.m.)	Avail. potash (K_2O) 6 ins. (p.p.m.)
(1) Sta Severa	III	200	8	6	1.4	38	5.6	0.9	0.09	39	101
(2) Las Hermanas (1) ...	III	240	12	7	2.8	46	5.5	1.9	0.13	11	74
(3) El Reposo (1) ...	III	250	12	8	2.8	25	6.0	2.1	0.15	13	88
(4) El Reposo (2) (3) ...	II	330	20	16	0.8	28	4.9	1.0	0.10	6	57
(5) River (1) (2) ...	II	400	20	18	1.7	22	6.2	2.1	0.15	20	55
(6) Poole	II	450	22	15	2.5	56	6.7	3.5	0.24	14	169
(7) San Juan (1) ...	I	500	12	12	4.0	28	6.4	4.0	0.27	28	219
(8) Ortinola	I	550	12	12	4.7	24	7.6	4.7	0.20	—	—
(9) San Juan (2) ...	I	650	20	18	1.7	41	6.7	2.0	0.17	48	140

Soil Types:
(A) *Sangre Grande Silty-Clay*: Las Hermanas (1); El Reposo (1); El Reposo (2) (3)
(B) *Ecclesville Clay*: Sta Severa
(C) *Montserrat Loam* (Brasso Sand): San Juan (1)
(D) *Montserrat Clay-silt* (Chocolate): San Juan (2)
(E) *River Fine Sand*: River (1) (2)
(F) *Maracas Sand* (colluvial phase): Ortinola
(G) *Princes Town Heavy Clay*: Poole

Productivity Rating:
Grade I Very high: over 500 lb. ac. yr.
Grade II: High; 500-330 do.
Grade III: Medium: 330-165 do.

against the depths of the mid-point of each layer. The depth of the 0.75 per cent. level of organic matter content was then read off from the graph. This critical value (0.75 per cent.) was arbitrarily chosen as marking the depth below which the effect of organic matter on soil properties appears to become insignificant.

In *Column* 5 is given the average content of organic matter in the humic layer.

In *Columns* 6 to 11 are given the mean values for soil constants customarily determined in the soils laboratory at the College, averaged for the top 12-inch layer.

Column 6; *Index of Texture* is derived by subtracting one-fifth of the content of coarse and fine sand (2.0-0.02 mm.) from the sticky point value. It assesses the degree of clayiness. Values range from 60 for heavy clays to *zero* for light sands.

Column 7; *Reaction* (pH) was determined by the quinhydrone electrode on 1 : 2.5 soil : water mixtures.

Column 8; *Organic matter* was measured by Watts's wet combustion method with chromic acid as oxidising agent. The value for carbon is multiplied by 1.724 and corrected by further multiplying by the arbitrary factor 1.33 in order to derive soil organic matter content.

Column 9; *Total nitrogen* was determined by the standard Kjeldahl method.

Column 10; *Available phosphate* was obtained by the Truog N/50 H_2SO_4 extraction method, and applying the coeruleo-molybdate indicator.

Column 11; *Available potash* was estimated as exchangeable K_2O extractable by N/2 acetic acid.

(2) Presentation of Results

An obvious feature of the data in Table III is the relationship which seems to hold between the main rooting layer and the organic status of the soil.

The sites fall into several categories with respect to the thickness of the zone in which the cacao root system is developed, as follows:—

(1) Shallow, nutrient-deficient clays

This category is exemplified by the Sta. Severa, Las Hermanas (1) and El Reposo (1), sites (Nos. 1, 2, 3, Table III), representing Ecclesville Clay and

Sangre Grande Silty-Clay, which are heavy, compact, markedly acid, base-deficient soils having greatly impeded underdrainage,* as indicated by the occurrence at each of the three sites of a conspicuous "gley", exhibiting brown and orange mottling on a pale blue-grey ground. The mottling begins at 5 or 6 ins., so that presumably the soil is often waterlogged below this depth, a supposition which is supported by the results of detailed investigations of aeration and water content that have since been carried out at one of the sites (Las Hermanas).† These results showed that, in the surface 6-ins. layer, adequate amounts of soil-air and soil-water are available *together and at the same time* only for a period of one-quarter of the year, namely, at the end of the dry season and the beginning of the wet season. During the rest of the year, aeration is deficient and conditions for root growth are presumably unsuitable. Further, the surface soil is liable to excessive wetness during most of the rainy season.

The nutrient status of these shallow clay soils is very poor; nitrogen content is medium-low, available phosphate very low, and available potash low, the amounts being inadequate (according to provisional laboratory standards) for satisfactory yields of cacao.

In view of such circumstances, it is not surprising that the root systems of cacao trees growing in these shallow waterlogged clays are mainly superficial.

At the *Sta. Severa* site, the laterals were all "relatively thin and long" and most occurred in the top 6 ins. of soil. The fibrous rootlets were "few and evenly distributed, particularly "in the uppermost part of the humic layer".

At the *Las Hermanas* (1) site, there was a thicker litter and the fibrous rootlets mostly occupied this material. Lateral roots here were "large and extensive", but "the "majority were concentrated in the top 6 ins".

At the *El Reposo* (1) site, the main laterals came off down to 8-ins. depth, but some smaller and shorter laterals were deeper-seated, though none came off below 18-ins., except near drains where they were deepest (30 ins.). The fibrous rootlets again "showed their greatest "development at or near the soil surface", being especially associated with organic mulch. It is noteworthy that the soil at this last site was deepest and possessed the best nutrient status.

Conclusions.—The chief features of cacao root-systems developed in shallow, nutrient-deficient, compact, waterlogged clays are:—

(i) Thick laterals lying close the surface where they are associated with decomposing litter or mulch.

(ii) Thin laterals lying deeper, though still mainly confined to the top 6 ins. of humic soil. They are relatively long.

(iii) Deep-seated laterals short and tortuous; they are associated with stiff non-humic mineral soil that resists root penetration.

(iv) Fibrous rootlets entirely confined to the upper part of the humic layer; they tend to form a distinct mat (locally called "*biché*") immediately below the leaf litter.

(v) Long tap-root, slender and tapering, tending to fork repeatedly at the lower depths.

(2) SHALLOW, NUTRIENT-DEFICIENT CLAYS, DEEPENED BY ROUND-RIDGING

The El Reposo (2) site (No. 4) is apparently different from the other El Reposo site (No. 1), although only 200 yards away and having the same type of soil (*Sangre Grande Silty-Clay*). The cacao beds at that site (Trees 1 to 5: Table I) were found to have been "round-ridged" according to a procedure commonly practised on flat alluvial lands in Trinidad, especially within the Sangre Grande basin where flooding is frequent and surface run-off sluggish. Round-ridging consists in the periodic addition of soil, dug out of the drain-trenches during clearing and deepening, to the centre of the bed which they surround, thereby gradually producing a camber. A rough loose stratification is thus imparted to the soil profile, whereby aeration and internal drainage are much improved. The deliberate incorporation of litter and prunings or of mulch or artificial manures (basic slag has been tried), or lime, where practised, doubtless helps in the general improvement. Greatly increased yields are claimed to have been obtained by round-ridging.

In the case in question, data indicating the changes that had taken place as a result of the round-ridging were obtained through special soil profile studies carried out in March, 1941. It was found that the depth of soil affected (*i.e.* the depth of accumulated soil at the middle of the bed) was about 20 ins., representing five distinct layers varying in thickness between 3 and 6 ins. The last addition of drain soil had been made in 1940. The organic content of the composite layers was 1.2, 0.9, 1.4, 1.2 and 0.9 percent. respectively (average 1.1 per cent.).

The appearance of the profile was irregular because of the upbuilding; patches of mottled grey "gley" could be discerned within the disturbed portion, though the general colouration was brownish-ochre, humic-stained in places. The soil was friable, finely-cracked, soft and slightly spongy. It showed no evidence, however, of deliberate addition of organic mulch, nor artificial manure, nor lime. Below, the undisturbed soil was easily recognisable by its orange mottling, its compact nature, its low organic content, and its high degree of acidity. In the case of the other El Reposo site examined by McCreary (El Reposo (3)), which was

* A Provisional Classification of the Soils of Trinidad; F. Hardy, *Tropical Agriculture*, 1940, XVII, pp. 153-158, with tabulated scheme.

† Studies on Aeration and Water Supply in Some Cacao Soils of Trinidad; F. Hardy, *Tropical Agriculture*; 1943, XX, pp. 89-104.

apparently located quite near to the last, the depth of the built-up soil seems to have been somewhat greater, being nearer 36 ins., since grey "gley" was conspicuous below that depth.

The thickness of the rooting zone was considerably greater at the disturbed (round-ridged) sites than at the undisturbed (flat) site (El Reposo (1)), namely, 20 ins. as compared with 12 ins.

> The cacao tap-roots were stouter but shorter (27 against 41 ins.) and less forked (Table I). The lateral roots were more numerous and better distributed in the built-up soil, and many came off at comparatively greater depths; branching was also more prolific. Fibrous rootlets showed "a very good distribution"; the presence of a regular superficial root-mat (*biché*) was not particularly noticeable at the round-ridged site; no specific mention of it appears in the records, and none was seen by the writer at the time of the profile sampling. Finally, it is noteworthy that the mean weight-ratio of stem to laterals *plus* small roots (Table I) was considerably greater for trees grown at the round-ridged site, namely, 4.1 against 3.6 (average weights; *round-ridged bed*; stem, 229lb.; roots, 56 lb.; *flat bed*; stem, 127 lb., roots, 35 lb.) A high ratio of stem to root is usually regarded as an index of healthy growth. The trees were said to have the same age, yet those grown on the round-ridged bed were heavier than those grown on the flat. The average yields of cacao beans of the two groups of trees were said not to differ appreciably, however, though this statement was not checked by measurement.

Conclusions.—The chief and presumably beneficial effects accruing from the round-ridging of shallow, nutrient-deficient, compact, water-logged clays, and attributable to increased aeration and freer drainage, appear to be:—

(i) Better and deeper distribution of laterals.
(ii) Lesser size-differentiation of laterals; appreciable reduction in length.
(iii) Increase in number of deeper laterals.
(iv) Greater proliferation of branching of laterals.
(v) Tendency for laterals to grow toward centre of cambered bed and away from drains (*See* Figure 1).
(vi) Suppression of root-mat (*biché*), and more even distribution of rootlets within the upper humic layer.
(vii) Shortening and thickening of tap-root.
(viii) Increase in relative weights of stem to roots, implying greater "efficiency" of the root system.

(3) Deep, nutrient-rich clays

This category is exemplified by the Poole and the San Juan (2) Rendzina sites (Nos. 6 and 9) which, however, show marked differences in drainage, so that the sites should be considered separately.

(*a*) *Poole.*—Here the soil (*Princes Town Heavy Clay*) is a stiff, plastic, black to grey, slightly acid, humic clay to 12-ins., below which it suddenly changes to bright yellow, slightly mottled, somewhat friable, alkaline clay, overlying, at 24 ins., dry, crumbly, rotten, pale-grey marlstone, becoming hard, nodular and conchoidally fractured below 5 ft. The parent rock contained 20 per cent. of calcium carbonate.

> The average organic matter and nitrogen contents of the surface foot are medium-high; available potash is adequate though not particularly high, but available phosphate is markedly deficient in this soil.

Underdrainage is free because of the undulating topography and the porous fractile nature of the parent material. On the other hand, drainage in the upper soil layers down to the 18 ins. is doubtless greatly restricted because of the imperviousness of the black and yellow clay. The soil at this site was quite typical of its class.

> The root system described by Mulloon for *Princes Town Heavy Clay* was characterised by a large number of woody laterals of which 32 were counted. The stoutest of these, 15 in number, occupied the upper 12 ins. highly humic layer. Their spread was about 10 ft. They were remarkable for their prolific branching and for the occurrence of dense tufts of fibrous rootlets at their extremities. The laterals occupying the transition layer between the humic soil and the plastic yellow clay were 12 in number and smaller in diameter; they also showed free branching; their extremities tended to rise into the more humic soil above. The remaining 5 laterals, occupying the bottom part of the yellow clay, were short but freely branched. They were straight, not tortuous as in the other clay soils.
>
> On the upgrade side of the tree (which was growing on a slope), the laterals were much stouter than on the other side. This feature is stated by an authority to be a "reaction to erosion", which accords with the view that Princes Town Heavy Clay in the Rio Claro District of South Trinidad has suffered in recent years from land-creep and sheet erosion* which have removed much of the humic soil, and in many places have thus brought the grey marl nearer to the surface.
>
> The surface of the soil at the Poole site at the time of root excavation was covered by a layer of leaf litter about one inch thick, within which a dense mass of fibrous rootlets was incorporated. According to Mulloon, "the whole formed a "mat which could be readily peeled off", but the source of the rootlets was an Immortelle shade tree and *not* cacao, since he states categorically that "cacao fibrous roots were "found to play no part in the formation of this "mat". This observation may have important bearing on the general question of root competition between these two commonly associated trees.
>
> Reference to Table I indicates that the total weight of lateral and fine roots (38 lb. per tree) was much less for the Poole site than for the El Reposo (2) site (56½ lb.) although the weights of the stems were nearly identical (226

* Soil Erosion in Trinidad and Tobago; F. Hardy, *Tropical Agriculture*, 1942, XIX, pp. 29-35.

and 220 lb.). Hence the weight-ratio between stem and root was larger for the Poole site (6.0 as against 4.1), which implies that the Poole soil was a better cacao soil than the El Reposo soil, even when improved by round-ridging.

(*b*) *San Juan* (2)—*Chocolate Soil.*—In this unusual kind of Rendzina soil, the deep humic clay is dark purplish-brown in colour and the underlying non-humic clay is bright ginger-brown instead of yellow. Its most striking characteristic is its remarkable crumb structure, which is stabilised by iron oxide cement so that it strongly resists dispersion by percolating water. The parent material consists of porous, soft, rotten sandstone of similar brown colour; it is sandier and more crumbly than rotten marlstone. The parent calcareous glauconitic rock is only reached at considerable depth. It is a typical Greensand. The drainage features are similar to those of the Princes Town soil, except that the upper part is more porous, so that water percolation throughout the profile is free and aeration plentiful.

The nutrient status of the soil at the site selected for root excavation was unfortunately not typical of Chocolate Soil, though its physical attributes appear to have been normal.

> Total nitrogen content was only 0.17 per cent. in the surface 12 ins., as against 0.25 per cent for average Chocolate Soil. Available phosphate was 48 p.p.m. and available potash 140 p.p.m., as against 283 p.p.m. and 309 p.p.m. for the normal. Many examples of Chocolate Soil contain three times these average amounts of phosphate and potash.

In respect of nutrient status, the Chocolate Soil site was somewhat poorer than the Princes Town Clay site, and much inferior to the best Chocolate Soil areas of the Montserrat District of Trinidad.

> The root system described by McCreary for Chocolate Soil was characterised by the relatively great depth of insertion of the *lateral roots*. One whorl of laterals was given off at the 4½ ins. level; these roots were large though few in number. Another whorl was given off at 13-15 ins.; the roots of this were more numerous though smaller in size, and branches from them descended deeply. The *tap-root* was short (only 31 ins.). The *fibrous rootlets* were "scattered over the soil surface"; they were "slightly concentrated in two spots" where a fallen log lay rotting on the ground, otherwise they were "evenly distributed through the "surface layers of soil". The apparent reduction in number of woody laterals and their comparatively large size, noted at the Chocolate Soil site, are usually associated with deep, well-drained, well-aerated and nutrient-rich soil.

Conclusions.—The chief features of cacao root systems developed in deep, nutrient-rich clays which distinguish them sharply from shallow nutrient-deficient clays, are:—

(i) Deep distribution of laterals, which are inserted as definite whorls, usually three in number, at regular depths in the tap-root, the stoutest being nearest the surface.

(ii) Relatively large number of laterals, though showing a tendency to reduction in numbers, decrease in length and increase in thickness where the soil is crumb-structured and well aerated.

(iii) Considerable proliferation of branching of laterals.

(iv) Absence of tortuous laterals implying unrestrained growth.

(v) Even distribution of fibrous rootlets and their extensive multiplication within the humic soil (especially in well-aerated, crumb-structured clay), and suppression of root-mat (*biché*).

(vi) Shortening and thickening of tap-root.

(vii) Increase in weight-ratio of stem to laterals *plus* fine roots, though the total weight of roots may be relatively small.

Many of these features have already been noted for root systems developed in compact clay soil (at El Reposo) whose aeration and depth had been considerably increased by round-ridging.

(4) Medium-shallow, nutrient-rich loams

This category is exemplified by the San Juan (1) site (No. 6), whose soil, however, is a compact fine sand, not really typical of Montserrat Loam. Its chief features are its high nutrient status and its fairly free drainage, dependent on undulating topography and increasing sandiness down the profile.

> The humic layer is 12 ins. thick, and its average organic content is highest of all (4.0 per cent.). Nitrogen and available potash contents are high, but available phosphate is low and near the border-line of deficiency.

The upper layers are hard and relatively impervious in this particular example, because of the well-known tendency of single-grained fine sand to compaction, so that downward percolation of water here is probably sluggish.

> The root system described by McCreary showed no new nor extreme features. It was noted that "the majority of the laterals "occurred in the top 6 ins.; a few smaller ones "occurred to a depth of 12 ins.; very few "penetrated deeper" (*i.e.* into non-humic soil). "The fibrous rootlets were distributed more or "less evenly over the surface of the soil in the "thin humic layer". This last feature, by analogy with the first soil category, may denote a tendency to texturally-impeded drainage within the upper layers.

Conclusions.—The records were not detailed enough to warrant definite conclusions. Lateral root distribution, as in cases previously considered, was confined to the humic soil, and fibrous rootlets occurred mostly on the surface, possibly because of somewhat impeded drainage at this site, which was perhaps not typical.

(5) Deep, medium-nutrient-rich sands

This kind of cacao soil is exemplified by the River Estate sites (1), (2), (No. 5), where root distribution was examined independently by

McDonald and McCreary. (The College site, where a young cacao tree was excavated by McCreary (Figure 4), also belongs to this category).

The soils are fine-sandy in texture, mid-brown in colour, and humus-stained to 12 or 18 ins. depth. The upper layer is usually compact and hard, especially in dry weather. Below, the colour is pale brown, orange or yellow, and the texture increasingly coarse. The deep subsoil may comprise either quartz mica sand or quartzose schist gravel. Hence, though the deep underdrainage is probably good, the internal drainage of the upper layers, because of the considerable degree of compaction, may be seriously impeded, unless the content of organic matter is sufficiently high to impart a porous structure which is not the case at either of the spots selected for root excavation.

> These facts are clearly substantiated by the results of detailed studies on aeration and water supply already mentioned, in which the fluctuations in soil moisture and aeration at a site in River Estate not far from the sites of the root excavations were especially investigated.* The results proved that, although the River Estate soil is regarded as a free-draining type, aeration is usually unsatisfactory during the rainy growing season, since both total amount of free air in the pore-spaces, as well as its content of oxygen, fall below accepted limits of adequacy. Aeration was shown to be generally worse in the second 6 ins. layer of soil than in the top 6 ins., and to be entirely absent at the 24 ins. depth. During rainy spells, however, the surface soil was found to retain water, so that it may be more often deprived of air than its own subsurface soil owing to percolation lag.

The moisture and air conditions vary considerably in River Fine Sand; they would not be regarded as altogether adequate for satisfactory root development, though different degrees of suitability may be presented by the several cacao fields which this soil-type comprises.

> The nutrient status of the soil at the sites of the excavations at River Estate and at the College was probably satisfactory with regard to nitrogen, but unsatisfactory with regard to available phosphate and potash, especially the latter, which is generally seriously lacking in the soils in question.

The root system described by McCreary for River Fine Sand differed greatly from that described by McDonald because its features had been markedly affected by the proximity of *mulch trenches*. One such trench, 2 ft. deep, which had been dug and filled with organic débris three years previously, was situated 4½ ft. from the tree, and another shallower trench, filled with cacao husks, had been dug 6 ft. away at right angles to the first. An open 2 ft. drain occurred 3½ ft. away on the opposite side to the first mulch-trench. In consequence, there were few fibrous roots on the soil surface, most of them being concentrated in the mulch-trenches where they were densely matted. Matted fibrous roots also lined the inside face and base of the open drain.

> According to McCreary's description of the River Estate site, *lateral roots* were numerous; 35 were counted in all. The stout ones, 9 in number, occurred in the upper 12-inch layer, together with 10 small ones; the rest of the small laterals occurred in the 13-18 ins. layer. The *tap-root* was well developed and penetrated to 48 ins. before forking.
>
> The development of the root system described by McDonald at River Estate presumably had not been affected thus by the presence of mulch-trenches. Nevertheless, the number of *laterals* here again was large, and again most occurred in the upper 12-ins. (Figure 3). Their spread was relatively short (6-10 ft.). The *tap-root* was well developed, as at McCreary's site. The *fibrous rootlets* mainly occupied the shallow surface humic layer, showing a tendency to form a root-mat.
>
> The young root system described by McCreary at the College site (Figure 4) also showed greatest development of *laterals* in the 12-ins. humic layer. The well-developed *tap-root* was deeply penetrating, and numerous inclined laterals and vertical anchor roots were traced down to 24 ins.
>
> Special aeration investigations carried out at the College site proved that fully adequate air-supply was available throughout the year, but that water-supply was very deficient in the dry season, the wilting point being reached early in this period.

Conclusions.—Cacao root systems developed in deep sands resemble somewhat those deveoped in deep crumb-structured clays having similar nutrient status, but the thickness of the rooting zone may be seriously restricted by a temporary high water-table where the sites lie on alluvial flats, that is, their depth may be reduced by topographically-impeded underdrainage. The root systems then tend to resemble those developed in shallow waterlogged clays; in particular, a marked root-mat or *biché* may occur on the soil surface.

The provision of *mulch-trenches* entirely alters the rooting habit of the cacao tree grown in sandy soil, in that it encourages the concentration and proliferation of fibrous rootlets in specific regions.

(6) SHALLOW, NUTRIENT-RICH SANDS

This is represented by the Ortinola site (No. 8) for which, unfortunately, we have no detailed information on soil composition. The soil profile, as briefly described by McCreary, consists of (i) a surface layer of rotting mulch (which had been deliberately applied to the field), merging

* (1) Studies on Aeration of Cacao Soils in Trinidad; H. Vine, H. A. Thompson and F. Hardy (I) *Tropical Agriculture*, 1942, XIX, pp. 175-180; (II) *ibid.*, pp. 215-223; (III) *ibid.*, 1943, XX, pp. 13-24; (IV) *ibid.*, pp. 51-56.

(2) Studies on Aeration and Water Supply in Some Cacao Soils of Trinidad; F. Hardy, *ibid.*, 1943, XX, pp. 89-104.

into rich humic soil, the whole being about 6 ins thick; (ii) an 18-ins. layer of pale-coloured sandy soil; (iii) a layer of gravel of unknown thickness. The total depth of the soil profile is thus limited to 24 ins. through the presence of this gravel.

The nutrient status, by analogy with similar soils examined elsewhere, is probably high with respect to nitrogen, but available phosphate, and specially available potash, might be inadequate.

The root system was mostly confined to the top 6 ins. of highly organic soil. The main whorl of *laterals* came off at 6 ins. A lower whorl, 12 ins. deep, consisted of small insignificant roots which turned vertically downwards into the gravel near the tap-root. The laterals showed wide spread. The *tap-root* was well-developed but it twisted and dwindled between 12 and 48 ins. within the gravel. *Fibrous rootlets* were evenly distributed in the upper 6 ins. humic layer, but no root-mat was evident.

Conclusions.—Here again the root system, including both woody laterals and fibrous rootlets, was developed mainly in the humic layer. Branches of the tap-root penetrated into the gravel, so that possibly they functioned as water-absorbing roots along with lower laterals that bend downwards into it from the non-humic sandy soil above.

(3) Discussion

Roughly quantitative relationships are revealed by the data in Table III between thickness of rooting zone and thickness of humic layer, and between productivity for cacao and both these dimensions, especially the latter. Fair relationship is also indicated between nutrient status of soil (that is, its content of available nitrogen, phosphate, potash and other essential substances) and productivity, though it is evident that laboratory chemical data alone are insufficient for the accurate assessment of the productivity rating of a cacao soil (or indeed of any soil producing a particular crop). This conclusion indeed had long ago been reached on general circumstantial evidence which has already been fully discussed by the writer.* It was early deduced that important factors other than the nutrient factor are involved in the definition of a highly productive cacao soil. Among these additional factors, sufficient water-supply, adequate aeration and ample root-room were especially stressed. Since soil water-supply and soil aeration are interdependent, and since both are largely controlled, not by chemical but by physical features of the soil (notable those decided by *soil structure*), cacao soil-types should be investigated by physical methods as well as by chemical analysis.

* The Maximum Yield of Cacao; A Discussion of Some Factors that Contribute to High Production; F. Hardy, *Tropical Agriculture*, 1939, XVI, pp. 179-191.

Water and air supply are also partly controlled by *topographical position*, since even open structured soil such as a loose sand, if low-lying, may become water-logged up to ground level by a rising water-table, whether this be permanent or only temporarily developed during a wet season. Thus, both soil structure and topographical position are involved in regulating root-room, for plant roots in general depend on adequate aeration for healthy growth and activity, as well as on freedom from mechanical hindrance to soil penetration for spatial spread and normal ramification.

Cacao soils may therefore only be fully assessed by reference both to nutrient status and to "*physiological depth*" of the rooting zone. By physiological depth is meant the thickness of the layer of soil that is adequately aerated and structurally suitable for the unrestricted growth of roots. Its magnitude might vary with season, for, in dry weather, a water-table may recede out of reach, or the effective air-space of a moist soil may be increased by evaporation, and thus become unblocked. Some actual measurements of these processes, previously referred to above, have already been published in this Journal. Where marked seasonal fluctuation in physiological depth occurs, the results may be deleterious in-so-far as diminishing depth may coincide with increasing seasonal demand by the plant for water, oxygen and nutrients, for example, when the crop is setting. Thus the extent of the time lag in the gradual onset of unsuitable water and air relations during the progress of the wet growing season may constitute an important characteristic of a cacao soil. Certain of the cases already studied clearly illustrate this contention. The importance of topographical site as an ecological sub-factor affecting root-room and its maintenance or otherwise throughout the year seems not heretofore to have been stressed.

The various topographical sites considered in this article fall into several roughly-defined categories. The least productive cacao soils are the "*physiologically shallow*" clays whose lack of root-room may be attributed to a temporarily high water-table during wet weather, induced by depressed topography or by drainage impedence due to impervious structure. The productive clays, by contrast, are "*physiologically deep*"; they possess an open structure, and drainage impedence is reduced through elevated topography and by the porous nature of the parent material. Some productive sands are also physiologically deep, although apparently, as at River Estate, fluctuating sub-soil water may seriously reduce their depth during the wettest part of the year by filling up the pore spaces.

(4) A Possible Special Rôle of Fibrous Rootlets

Apart from the characteristic features of tap-root and laterals developed by cacao-trees growing in soils of differing physiological depth and

nutrient status, the quantity and distribution of *ibrous rootlets* in the various soil-types appears to be highly significant.

Customarily, these fine roots are referred to by planters as "feeding roots", but, although they may partly function in such manner (being usually closely associated with rotting surface litter, vegetable mulch or incorporated soil organic matter), it now seems likely that they exercise another, even more important, function in addition, namely, the manufacture of a specific growth-promoting substance or hormone that has tentatively been named "caulocaline", essential for satisfactory stem development. This suggestion is based on certain investigations recently carried out on the tomato plant by F. W. Went at the California Institute of Technology, U.S.A., and referred to by Prof. E. E. Cheesman in this Journal,* who has pointed out its possible bearing on cacao tree growth.

According to Went, "in many plants caulo-" caline is formed only in "roots surrounded by "moist air"; abundant soil aeration is thus not "required solely for water and nutrient uptake "(which requirement is relatively small), but for "increasing the growth rate of the stems and "preventing chlorosis". Went states that "many "plants require a very light and loose top soil."

"If the upper soil layers are allowed to pack "closely together, growth in these plants is "stunted. Although in most plants, the roots "(especially those taking up water and salts) are "located deep down in the closely-packed soil, "still a superficial cultivation of the soil around "such a plant will decrease growth if the "superficial roots have been injured".

These observations may have considerable bearing on the causes of deterioration of cacao soils in Trinidad, and may suggest means for their resuscitation if it can be proved that they do indeed apply to the cacao tree. The evidence adduced in this article, demonstrating the close relationship between the morphological features and distribution of cacao root systems and soil characters, clearly indicates that the extent and disposition of their complement of fibrous rootlets are significantly important in the question of root adequacy.

Thus, where the soil is shallow, compact and waterlogged, satisfactory growth may be attained only when the cacao root system includes a dense fibrous root-mat closely associated with an abundant rapidly rotting litter or surface mulch properly protected from injury and destruction due to surface erosion or desiccation, and from compaction caused by beating rain. At the other extreme, where the soil is deep, porous and well drained, the same result is realised by the greater dispersion of fibrous rootlets downwards throughout the whole of the well-aerated upper layer, which, in the most satisfactory cacao soils of this class, is usually relatively thick, highly humic and rich in nutrients. Cacao root systems developed in such highly desirable soils are less liable to damage, and the soils are notable for their stability, reliability and great permanence of fertility.

* F. W. Went; *Plant Physiology*, 1943, XVIII, pp. 51-65. See *Tropical Agriculture*, 1943, XX, pp. 85-87. Editorial.

Summary

(1) This article presents the results of preliminary studies of the root system of cacao grown in several contrasted soil-types in Trinidad. The excavation method was used.

(2) An attempt has been made to correlate the morphological features, depth of penetration and distribution of the root system with the chief physical and chemical characteristics of the soil, in particular, the thickness of the humic layer and the contents of nitrogen, available phosphate and potash, as well as drainage and aeration as decided by structure, texture and compaction of the soil, and by topographical position.

(3) The following contrasted cases have been identified and discussed:—(*a*) shallow, nutrient-deficient clays, (*b*) the same, deepened by "round-ridging", (*c*) deep, nutrient-rich, open-structured clays, (*d*) medium-shallow, nutrient-rich loams, (*e*) deep, medium-rich sands, and (*f*) shallow, nutrient-rich sands.

(4) Relationships between thickness of rooting zone and of humic soil, and between each of these dimensions and productivity for cacao, have been revealed by the field and laboratory data.

(5) Distinction has been drawn between "physiologically shallow" and "physiologically deep" cacao soils, in which the features of the root system are different and characteristic. The first is represented by (i) compact clay soils occupying both flat and undulating topography, and (ii) sandy soils occupying low-lying sites. Here shallowness is due to drainage impedence caused by an impervious soil structure or by a high water-table. The second is represented by (i) crumby clay soils, and (ii) sandy soils occupying elevated and undulating topography where under-drainage is free and the water-table low.

(6) The cacao root system developed in *physiologically shallow* soils is mainly superficial, (being confined to the top 6 ins.), and is characterised by (i) a dense mat of superficial fibrous roots (*biché*) closely associated with leaf litter or mulch, (ii) long, thin, forked tap-root, (iii) long laterals, diminishing greatly in length and thickness with depth.

(7) The root system developed in *physiologically deep* soils is well dispersed; it is characterised by (i) the absence of a superficial root-mat (*biché*), (ii) short, thick tap-root, (iii) short laterals, coming off in whorls to the full depth of humic soil, (iv) free branching of laterals which terminate in tufts of fibrous rootlets evenly distributed throughout the porous soil.

(8) The *fibrous rootlets* develop profusely only in well-aerated organic soil, litter or mulch; they may have a special function in manufacturing a hormone essential for normal healthy growth of the cacao tree.

CRITERIA FOR TRICHOGRAMMA

BY

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CRITERIA for the minute cosmopolitan parasitic wasp, *Trichogramma minutum* Riley, should not differ fundamentally from those applied to any other parasite or predator on a specific host. *Trichogramma* is not a special case. As with any other insect, its activities are circumscribed by certain limitations of temperature and humidity, which are possibly of greatest importance in the temperate zone and semi-tropical regions. In the tropics, however, specifically in the coastal cane-growing regions of the West Indies, its activities, to quote a statement by Dr. J. G. Myers (1) applying generally to all tropical insects, are " shaped largely by biotic environmental factors, the influence of physical factors being much less significant ". All *Trichogramma's* minor biological requirements are met naturally in any tropical cane field; its only major requirement is an abundance of host egg-clusters. Aside from a very limited competition with predators and a parasite for host eggs, this comprises the entire extent of the influence of environment on *Trichogramma*. For five years, the writer assisted by Dr. Luis F. Martorell, has been making field observations on the natural conditions of parasitism by *Trichogramma* on the egg-masses of *Diatraea saccharalis* F. in the cane fields of Puerto Rico (2) and conducting tests on the effect of releases of laboratory-reared material (3). It has taken two years to summarize the rather extensive results, and to become convinced that all are subject only to the above general statement of principles.

Inherent in biological control by parasites and specific predators, and even by entomogenous fungi, is a preliminary requirement of a reasonable number of hosts before it can become operative at all. Also, there is a tendency for control to become increasingly effective as the number of individuals of the specific host becomes greater. Our observations of *Trichogramma* indicate that no matter how these may be grouped, by month, by locality, or by any other factor, the average invariably shows increasing natural parasitism as the number of host eggs increases. Because of its short life-cycle and of its almost universal distribution, *Trichogramma* reacts promptly to an abundance of host eggs, and normally one may expect a perfection of control directly in proportion to the abundance of the host. This seems to leave no loop-hole for the need of artificial distribution, and in fact none exists normally. It is the exceptional fields only, which despite an abundance of egg-clusters, lack a comparable abundance of parasites, that can be favourably affected by parasite releases. During the months of June, July and August in Puerto Rico, such exceptional fields are so rare that for practical purposes they do not exist. Increasing in autumn, reaching a peak in December, and dropping rapidly in spring, the number of such fields is never large, yet it is only in such fields that the release of laboratory-reared *Trichogramma* can be justified commercially.

The extreme advocates of the benefits of *Trichogramma* releases claim that nothing is lost even if releases are made in fields where only a few unparasitized host eggs are present: the parasites will seek out such egg-clusters, and control will attain total effectiveness. Actual releases show no such results where host eggs are scarce. Theoretically, the continued existence of the parasite depends on its finding such marginal egg-clusters, but in fact it appears to be much more easily discouraged than entomologists in looking for that final unparasitized egg-cluster.

The fields of sugar cane around the coasts of Puerto Rico offer an exceptional opportunity for studying the natural activities of *Trichogramma*, for the limitations imposed by weather do not operate at all on oviposition by its host, and only to a very minor degree upon the egg-parasite. To obtain the maximum yield of sugar, all cane fields in xerophytic Puerto Rico and many even in the humid regions are irrigated liberally, so that an approximation of optimum humidity is maintained throughout the year regardless of rainfall. The slight seasonal variations in temperature do have an effect on *Trichogramma*, however, even if not on its host. Summer mean temperatures of 80°F., or slightly higher are apparently optimum for the parasite, at which time it attains maximum abundance in all cane fields; the slightly lower average mean winter temperatures of a few degrees below 80°F. sometimes allows an abundance of host eggs to occur without a corresponding abundance of parasites. This happens in at most a third of the fields in one or two localities, more often a fourth or fifth or an even smaller fraction at other points on the xerophytic south coast. In the regions where such abnormal fields occur most often, no seasonal pattern of abundance and scarcity of host eggs is to be observed, thus one may conclude that both temperature and humidity are optimum for *Diatraea* oviposition at all times of year. Only in the north western corner of the Island does a rapid increase in host eggs in the spring give even the appearance of a seasonal pattern of host abundance, and this is so closely paralleled by high parasitism by *Trichogramma* and drops so suddenly in late summer, long before any decline in temperature occurs, as to indicate the near perfection of natural control of *Trichogramma* alone, uncomplicated to the least degree by other biotic factors.

Moth borer oviposition is certainly not limited by lack of a host (as is that of its parasite much of the time), for cane fields occupy practically all of the land available for cane culture. What stimulus to oviposition is lacking therefore, and why are *Diatraea* eggs scarce so much of the time? Apparently no stimulus is lacking, and the scarcity of moth borer eggs is due to a scarcity of female moths to lay them. The scarcity of *Diatraea saccharalis* appears to be due to an approach to perfection of natural biological control. This near perfection of biological control is not due exclusively to *Trichogramma*, which accounts for less than half the eggs, nor to another egg-parasite, *Prophanurus alecto* Crawford, which is found only when host eggs are exceptionally numerous, but is also due to a fifth of the eggs being eaten by the ant, *Monomorium carbonarium ebeninum* Forel, to high mortality of the larvae before they become established within the host, to larval parasitism by Tachinid flies, and to various minor miscellaneous causes. All of these add up to an approximation of perfection of biological control of the sugar-cane moth borer in Puerto Rico, or at least so we must conclude if, despite optimum temperatures and humidity throughout the year plus an abundance of favoured host plant, only rarely do egg-clusters occur in sufficient numbers to indicate an abundance on the insect.

As so many factors enter into the production of biological control, the number of combinations is infinite of degrees of effectiveness with which each may operate. Just how or when these combinations will result in scarcity or abundance of eggs cannot be predicted. It is obvious, however, that peaks of abundance of *Diatraea* egg-clusters will follow no seasonal pattern, or of variations in weather, for they do not depend upon season or weather, but upon abundance or scarcity of parasites and a predator, which also do not depend upon season or weather, but primarily upon abundance of their specific host: the moth borer egg, or the moth borer larva.

The just-hatched larvae of the moth borer drift long distances with the wind, while the moths can fly in any direction, and *Trichogramma* tends to disperse with the prevailing winds, as well as to drift with local off-shore and on-shore air-currents. Thus, neither parasite nor host is fixed in place, and any result of planting *Trichogramma* in any one place tends to diffuse and disperse gradually into and out of surrounding fields to such an extent that one may well question any apparent result claimed to be apparent in difference of stalk injury between release and adjoining check field that may be reported when the cane is harvested. The stalk of sugar cane that goes to the mill to be ground represents the result of from ten to sixteen months of growing season. The total life-cycle of the moth borer is completed in from forty to sixty days. Most temperate zone crops have to be protected against one, or at most two broods of their insect pests; sugar cane against eight possible generations of the moth borer. How unlikely, therefore, that the release of laboratory-reared egg-parasites to attack the egg-clusters of the first generation of the moth borer will continue to be felt through seven succeeding generations, and finally, ten to sixteen months later, be reflected in a measurable decrease in stalk injury. The only proof of the value of releases is much more immediate. Within the next few days or weeks after the release, its effect should be apparent in a marked increase of parasitism, as compared with all the other non-adjacent fields of the same region used as checks. Given the required conditions of little or no natural parasitism and a large number of fresh egg-clusters, the results will be promptly and immediately obvious. Weather and season are immaterial; the only pertinent conditions are absence of *Trichogramma* naturally, and abundance of fresh host eggs. Find such exceptional conditions promptly, and the success of *Trichogramma* releases is assured, but it is only under such conditions that releases have any chance of being of commercial value.

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A NEW SOURCE OF PECTIN

Practical importance may be attached to the discovery, reported by T. P. Ghose and S. Krishna in *Indian Forest Leaflet* No. 23, 1942, from the Forest Research Institute, Dehra Dun, that the seeds of *Tamarindus indica* contain a very high proportion of pectin (some 58 per cent. of the kernel being obtained as a crude alcohol pecipitate). The tamarind is cultivated throughout India, Burma and Ceylon, mainly for the sour fruit, an enormous quantity of which is consumed; at present the seeds are usually thrown away, so that if arrangements can be made for their retention and collection a low-priced source of pectin should be available and one which permits readily of storage and transport until such time as it is convenient to extract the pectin. Particulars are given of a method of extraction and isolation of the pectin, which readily forms a firm jelly with suitable proportions of sugar and citric acid.—(*Nature*, Vol. 152, No. 3844.)

PHOSPHATE FIXATION—AN EXCHANGE OF PHOSPHATE AND HYDROXYL IONS

The removal of phosphates from solution when a soluble phosphate is brought into contact with certain soils has been termed "phosphate fixation." The exact nature of this removal has been the subject of much consideration and study by soil specialists. To the practical farmer, a means of preventing excessive phosphate fixation in soils is important. To any scientist who is interested in the physicochemical phenomena of soils as well as the complex soil-plant systems whereby plants absorb nutrients, a knowledge of the mechanism of phosphate fixation in soils is likewise of primary interest.

A review of the literature leaves one somewhat confused. Whether phosphate fixation is due to chemical precipitation, to adsorption or to both is not clear. It is recognized that phosphates are precipitated as calcium phosphates in alkaline soils, but these salts are soluble enough to supply phosphorus for plant growth, unless fluorine and carbonates are present in sufficient quantities to form very insoluble fluoroapatite and complex calcium phospho-carbonates.

Until recently, chemical precipitation was considered the primary cause of phosphate fixation in soils. The precipitation has been attributed largely to calcium and magnesium in calcareous soils and to iron, aluminium, and manganese in acid oils. In the latter, it was thought that fixation of phosphate was due to a simple precipitation of $FePO_4$ and $AlPO_4$. Truog (1) and McGeorge and Breazeale (2), however, have shown that the normal phosphates of iron and aluminium are readily available to plants. Their findings seem to eliminate the idea of simple precipitation as an explanation of phosphate fixation because even relatively acid soils are low in soluble iron. An explanation of phosphate fixation on the basis of adsorption has been proposed. Since hydrated oxides of iron and aluminium found in soils have colloidal properties, adsorption of phosphate is probable. Instead of using the confusing term "adsorption" to designate this colloidal mechanism of phosphate retention, Mattson (3), Pugh (4), (5), and Ravikovitch (6) (7) have used "anion exchange." By this term they mean that phosphate is substituted on the colloidal complex in place of some other anion, which is in solution in smaller quantities or which does not possess enough energy to hold its position on the colloidal complex in competition with the very active phosphate ions.

Stout (8), working with aluminosilicate minerals, kaolinitic in type, showed that there is a reversible ionic exchange between phosphate and hydroxyl ions. He was able to show a definite change in the crystal structure of kaolin due to phosphate fixation and, furthermore, to measure the amount of water formed when phosphate was fixed from a H_3PO_4 solution. This indicated that hydroxyl ions which were definite components of the crystal structure were replaced by phosphate ions.

Murphy (9) found that kaolinite fixes large amounts of phosphate but only when the mineral is very finely ground. It is quite evident that this intense grinding exposes a considerable number of hydroxyl ions which become active in fixing phosphate by an anion exchange reaction.

Most soils contain a considerable amount of iron oxide distributed as a film over individual soil particles. This is especially true of the lateritic and podzolic soils (B-horizon). Though this hydrated iron oxide is not in solution, its colloidal nature and its surface position on soil particles make it very active in fixing any soluble phosphate that comes in contact with it. Data presented in this paper indicate that phosphate fixation is a physico-chemical exchange of phosphate ions for these exposed hydroxyl ions. Though this seems to be an equilibrum reaction, in soils it is greatly shifted toward phosphate fixation, because of the very low hydroxyl-ion concentration in the soil solution and the high hydroxyl concentration of the hydrated ferric oxides on the surface of the soil particles. Kaolin fixes phosphate only when it is finely ground to expose active hydroxyl ions. Ferric hydroxide, finely ground kaolin, and a podzol B-horizon were found to fix large amounts of phosphate in an unavailable form. When a suspension of any of these materials was mixed with soluble phosphate of similar pH value, the resultant mixture increased in pH value. This is taken to indicate that phosphate ions replaced the hydroxyl ions.

Dehydration and removal of hydroxyl ions by high temperatures greatly reduced the phosphate-fixing capacity of soils and of hydrated iron oxide. The reverse is true for hydrated aluminium oxide.

Removal of active iron and aluminium oxides also greatly reduced the capacity of soils to fix phosphate.

Both silicate and fluoride ions are capable of replacing hydroxyl ions, as evidenced by pH changes. The beneficial effect of silica on plant growth may be due to its ability to remove fixed phosphate or to replace the hydroxyl ions and thus decrease phosphate fixation.

*Abridged from an article by Joseph B. Kelly and A. R. Midgley which appeared in *Soil Science*, 1943, Vol. 55, p. 167.

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CHEMICAL NOTES

(Compiled by the College Department of Chemistry and Soil Science)

Dehydrated Molasses

The development of a process for dehydrating molasses and packing it in dry form has been announced by the United States Board of Economic Warfare. Among other results, the process is expected to make possible the movement of a larger volume of molasses from Caribbean producing areas to the United States, because the solidified molasses will require much less shipping space and can be shipped as ordinary cargo. The new process is considered important in the war emergency both because tank storage facilities for molasses in the Caribbean area are taxed to capacity and because a tanker ship shortage is seriously limiting the shipment of fluid molasses to the United States, where it is needed for the distillation of alcohol for the munitions industry. It is estimated that there are between 200 million and 220 million gallons of molasses in storage in Cuba, 60 million gallons in the Dominican Republic, 65 million in Puerto Rico, and between 25 and 30 million in Haiti.

The dehydration process can be carried out at sugar mills with the simplest of equipment and at small cost. Finished solid blocks of molasses can be stored for indefinite periods in ordinary warehouses or sheds, and can be shipped, handled and stored as general dry cargo. The dehydrated molasses will not spoil, and requires 40 per cent. less shipping space than fluid molasses. Molasses treated by the new process is suitable, when reconstituted, only for the manufacture of commercial alcohol, and not for feeds. The process so far has only been tried experimentally, on a small scale, and it undoubtedly will be necessary for interested companies to do further experimenting before venturing on large-scale production. Further information on the process may be obtained from the General Commodities Branch of Imports, Board of Economic Warfare, Washington. (*Abstract from Sugar*, XXXVIII, No. 7, 1943.)

* * *

Soil Erosion Control in Jamaica

In an article which was published in the *Jr. Jamaica Agric. Soc.*, 46: 211-3, methods of erosion control suitable for Jamaican conditions are suggested. Barrier grasses should be planted along the contours, the vertical distance between barriers should not exceed 4 ft. on gentle and 5 ft. on steeper slopes instead of the 6-8 ft. originally recommended. The digging of small benches and planting grass on the lower side is not a suitable method. Notes are given to assist the choice of grass. The barriers must be carefully and closely planted, well pressed with the foot and mulched. Bare earth will later appear below the barrier; this must be planted up with another row of grass, using the original row as a source of plant material. Gaps in the grass must be immediately replanted or gullies will develop between the stools. Wall barriers can be built but require constant maintenance. Steep slopes usually left uncultivated elsewhere must be used in Jamaica. The most practical method seems to be the use of alternate contour strips of equal width crop and barrier grass or cover crop, the width of each strip not exceeding 1/3 chain. Two serious obstacles have been encountered in inducing cultivators to adopt anti-erosion methods. The first is insecurity of tenure, the second the waste of ground involved by the barrier strips. These, being unfenced, cannot be grazed unless the cattle are tethered.—(*Horticultural Abstracts*, XIII, No. 2.)

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Effect of Fallowing

According to the 1941 Annual Report of the Director of Agriculture, Cyprus, preliminary investigations on the effect of fallowing on soil moisture and soil nitrogen indicated that while there was no apparent effect on the moisture content, the quantity of soluble nitrogen present in October (*i.e.*, at the end of the dry summer season and just before sowing time) is five to six times as great in land which had been fallowed in the previous winter and during the summer as in land which had borne a crop during that winter.—(*Soils and Fertilizers*, VI, No. 2.)

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Dried Citrus Pulp in Beef Cattle Fattening Rations

In trials described in Bull. 613 of the Texas Agricultural Experiment Station it was found that a mixture of 75 parts ear corn chop with husk and 25 parts dried citrus pulp consisting of grapefruit peel, rag and seed as the carbohydrate concentrate proved a satisfactory fattening ration for bullocks. Results from the use of 40 per cent. or higher quantities of pulp were not so satisfactory.